1

COMMUNICATION UNIT AND METHOD OF CHANNEL ESTIMATION IN AN
OFDM COMMUNICATION SYSTEM

FIELD OF THE INVENTION

5

This invention relates to an estimation of radio-channel
propagation conditions, in order to equalise their effect
on transmitted data. The invention is applicable to
improving an accuracy of channel estimation in an
10 orthogonal frequency division multiplex (OFDM) wireless
receiver.

BACKGROUND OF THE INVENTION

15 Wireless communication systems, for example cellular
telephony or private mobile radio communication systems,
typically provide for radio telecommunication links to be
arranged between a plurality of base transceiver stations
(BTSs) and a plurality of subscriber units, often termed
20 mobile stations (MSs).

Wireless communication systems are distinguished over
fixed communication systems, such as the public switched
telephone network (PSTN), principally in that mobile
25 stations move between BTS (and/or different service
providers) and in doing so encounter varying radio
propagation environments.

Methods of communicating information simultaneously exist
30 where communication resources in a communication network
are shared by a number of users. Such methods are termed
multiple access techniques. A number of multiple access

2

techniques exist, such as frequency division multiple
access (FDMA), time division multiple access (TDMA), and
code division multiple access (CDMA).

5   The communication link from a BTS to a MS is referred to
as the down-link. Conversely, the communication link
from a MS to the BTS is referred to as the up-link.

In wireless communication systems, there is a need to
10   estimate the effect caused by the 'wireless communication
channel' on the data being transmitted. Channel
estimation is required so that the received data can be
equalised to reduce, restore or minimise signal
degradation caused by such transmission channel
15   impairments. A radio channel is said to be equalised if
the channel impairments can be eliminated or
significantly reduced.

In the field of this invention, the most conventional
20   strategy in estimating radio channel propagation
conditions is to model the radio channel by a finite
impulse response (FIR) filter. The channel estimation is
typically performed by periodically transmitting a known
data sequence, generally referred to as a training
25   sequence, over the desired radio channel. Such training
sequences are a-priori known by the receiver. The
training sequence is extracted from the received, desired
data stream and is used to compute channel estimates.

30   In the field of this invention, namely that of Orthogonal
Frequency Division Multiplexed (OFDM) systems, also
termed multi-carrier systems, the data stream is divided

3

into several (N) sub-streams. These sub-streams are
transmitted on 'N' orthogonal sub-carriers at different
frequencies, for example by means of an inverse fast
Fourier transform (IFFT) at the transmitting unit.

5

One of the main advantages of OFDM systems is their very
simple equalization scheme, which is reduced to a
multiplication of the FFT outputs (of each carrier
frequency) by the frequency domain channel coefficients.

10 Of course, the true channel coefficients are unknown, and
have to be estimated. As an illustration, the mean
square error between the true channel coefficients and
the channel coefficients at time 0 (time 0 being chosen
when a training symbol is received) is plotted in

15 function of time on FIG. 1, for an HIPERLAN/2 channel
with a mobile terminal moving at 3m/s.

Referring now to FIG. 2, a classical Bit interleaved and
convolutionally coded (BICC) OFDM system 200 is shown.

20 The BICC OFDM system 200 includes a BICC OFDM transmitter
210. The BICC transmitter 210 receives a data stream 212
d_i and convolutionally codes 215 the data stream to
produce an output b_i 217. The convolutionally coded
output b_i 217 is input to a bit interleaver 220. The

25 output from the bit interleaver 220 is then input to a
mapping function 225, which associates a subset of bits
x_k 228 to a location on a constellation. The type of
constellation generated by the transmitter 210 is
dependent upon the modulation scheme employed by the OFDM

30 modulator 230. The OFDM modulator then outputs the OFDM
modulated signal over the communication channel 235.

4

A BICC OFDM receiver 250 receives the OFDM modulated
signal over the communication channel 235. In effect,
the receiver 250 performs the inverse operations of the
5   BICC OFDM transmitter 210. In this regard, the receiver
250 includes an OFDM demodulator 255 to translate the
received constellation locations into a sequence of bit
subsets. The bit subsets are then input to a demapping
function 260. In the demapping function, bit metrics are
10 computed to feed the Viterbi decoder 270. This
computation involves the frequency channel coefficients,
which must be estimated periodically. A bit de-
interleaving function 265 arranges the received bit-
stream for decoding in the Viterbi decoder 270.

15

The above receiver arrangement presents a number of
significant drawbacks. In particular, the process to de-
map, decode and perform channel estimation separately, as
three distinct and independent functions, only enables
20 the respective individual operations to be optimised.

In J. Boutros, C. Lamy , F. Boixadera, "Bit-interleaved
coded modulation for multiple-input multiple-output
channels",IEEE ISSSTA , Sept. 2000, a method performing
25 joint de-mapping, decoding and channel estimation using
an estimation-maximisation (EM) algorithm and a turbo-
demodulation procedure has been proposed. However, the
proposed algorithm has been derived in a single carrier
context and is therefore unsuitable for OFDM
30 implementation.

5

A turbo channel estimation method using EM algorithm in
an OFDM context has been proposed in E. Jaffrot, M.
Siala, "Turbo channel estimation for OFDM systems on
highly time and frequency selective channels", Proc.
5   ICASSP2000. However, the channel estimation method
assumes, as a pre-requisite, a phase-shift keyed (PSK)
modulation scheme. As such, the method is limited in its
applications and works only for binary PSK (BPSK) and
quadrature PSK (QPSK) mapping. Thus, it cannot be
10 applied to high bit rate applications such as HIPERLAN/2
(which uses a quadrature amplitude modulation (QAM)
scheme). Moreover, it uses pilot carriers, which reduces
the application bit rate.

15 Thus, there exists a need in the field of the present
invention to provide an improved channel estimation
method in an OFDM communication system, wherein at least
some of the aforementioned disadvantages may be
alleviated.
20

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a graph of mean square error (MSE)
for a BRAN A channel with a mobile terminal (MT) moving
25 at 3m/s; and

FIG. 2 shows a simplified processing block diagram of a
bit-interleaved and convolutionally coded OFDM
communication system.
30

6

Exemplary embodiments of the present invention will now
be described, with reference to the accompanying
drawings, in which:

5   FIG. 3 illustrates a wireless communication unit adapted
in accordance with a preferred embodiment of the present
invention;

FIG. 4 illustrates a channel estimation model applicable
10 to the preferred embodiment of the present invention.

FIG. 5 illustrates a block diagram of a decoding unit
adapted in accordance with a preferred embodiment of the
present invention;

15

FIG. 6 illustrates two examples of mapping that can be
used in the preferred embodiment of the present
invention;

20 FIG. 7 illustrates a model of an OFDM system used in the
preferred embodiment of the present invention;

FIG. 8 illustrates a block diagram of a decoding unit's
forward-backward algorithm in accordance with a preferred
25 embodiment of the present invention; and

FIG. 9 shows bit-error-rate simulation results of the
channel estimator according to the preferred embodiment
of the invention.

30

DESCRIPTION OF PREFERRED EMBODIMENTS

7

In summary, the preferred embodiments of the invention
described below perform blind channel estimation for each
OFDM symbol, which allows the receiver to track the
channel variations, and consequently to increase the time
5   between training sequences. In particular, the channel
estimate of the frequency channel coefficients for each
OFDM symbol is performed using an Expectation-
Maximization (EM) algorithm that includes estimated
channel coefficients using at least one other, and
10   preferably all the other sub-carriers.

Referring now to FIG. 3, there is shown, by way of
example, a block diagram of a wireless communication
unit, adapted to support the inventive concepts of the
15   preferred embodiments of the present invention. The
wireless communication unit 300 contains an antenna 302
preferably coupled to an antenna switch 304 that provides
isolation between a receiver and a transmitter chain
within the wireless communication unit 300.
20

The receiver chain shown includes receiver front-end
circuitry 306 (effectively providing reception, filtering
and intermediate or base-band frequency conversion). The
front-end circuit 306 is serially coupled to a signal
25   processing function 308. An output from the signal
processing function is provided to a suitable output
device 310.

The signal processing function 308 performs all signal
30   processing functions for the wireless communication unit
300, including demodulation, de-mapping, bit de-
interleaving, channel estimation and decoding. In

8

accordance with the preferred embodiments of the present
invention, the signal processing unit 308 has been
adapted to perform EM-based channel estimation, using
probabilities on coded bits. These probabilities may be
5   provided by any channel decoding scheme yielding soft
outputs, e.g. a so-called BCJR algorithm – see L. Bahl,
J. Cocke, F. Jelinek and J. Raviv, "Optimal Decoding of
Linear Codes for Minimizing Symbol Error Rate", IEEE
transaction on Information Theory, March 1974. The
10   preferred embodiment uses a turbo-demodulation process,
such that it is able to jointly perform de-mapping and
decoding of the received signal. The signal processing
function 308 is further adapted inasmuch as it employs a
new channel estimation method, as is further described
15   with regard to FIG. 5.

The receiver chain shown also includes received signal
strength indicator (RSSI) circuitry 312 (shown coupled to
the receiver front-end 306, although the RSSI circuitry
20   312 could be located elsewhere within the receiver
chain). The RSSI circuitry is coupled to a controller
314 for maintaining overall subscriber unit control. The
controller 314 is also coupled to the receiver front-end
circuitry 306 and the signal processing function 308
25   (generally realised by a digital signal processor (DSP)).
The controller 314 may therefore receive bit error rate
(BER) or frame error rate (FER) data from recovered
information. The controller 314 is coupled to the memory
device 316 for storing operating regimes, such as
30   decoding/encoding functions and the like. A timer 318 is
typically coupled to the controller 314 to control the
timing of operations (transmission or reception of time-

9

dependent signals) within the wireless communication unit
300.

As regards the transmit chain, this essentially includes

5   an input device coupled in series via transmit signal
processor 328 to a transmitter/ modulation circuit 322.
Thereafter, any transmit signal is passed through a power
amplifier 324 to be radiated from the antenna 302. The
transmitter/ modulation circuitry 322 and the power

10   amplifier 324 are operationally responsive to the
controller, with an output from the power amplifier
coupled to the duplex filter or circulator 304. The
transmitter/ modulation circuitry 322 and receiver front-
end circuitry 306 comprise frequency up-conversion and

15   frequency down-conversion functions (not shown).

Of course, the various components within the wireless
communication unit 300 can be arranged in any suitable
functional topology that is able to utilise the inventive

20   concepts of the present invention. Furthermore, the
various components within the wireless communication unit
300 can be realised in discrete or integrated component
form, with an ultimate structure therefore being merely
an arbitrary selection. The preferred decoding and

25   channel estimation function can be implemented in
software, firmware or hardware, with the function being
implemented in a software processor (or indeed a digital
signal processor (DSP)) that performs the decoding
function, merely a preferred option.

30

The transmitter signal processor 328, which is shown as
being distinct from the receiver signal processor 308 for

10

clarity purposes only, includes a convolutional encoder
or a turbo-coding function.

In accordance with a preferred embodiment of the present
5   invention, an improved channel estimation algorithm for
the OFDM system is included. The channel estimation uses
an Expectation-Maximisation (EM) algorithm. This is a
parametric estimation algorithm, which attempts to
estimate the parameters 'θ' 404 of a system 400 from the
10 observations of its output y 406 blindly without knowing
its input x 402, as shown in the model in FIG. 4.

The EM algorithm is an iterative procedure, which
maximizes the likelihood function in two steps:
15

A first Expectation step (E-step): which comprises a
computation of:

$$E_x\left[P(x\,|\,y,\theta^{(p)})\right] \qquad\qquad [1]$$

20 and

A second Maximization step (M-step):

$$\theta^{(p+1)} = \arg\max_{\theta} P(y\,|\,\theta,\hat{x}^{(p)}) \qquad\qquad [2]$$

25

In a practical implementation, the maximisation (M-)step
is performed by maximizing the auxiliary function:

$$Q(\theta,\theta^{(p)}) = E_x\left[\log P(x,y\,|\,\theta)\,|\,y,\theta^{(p)}\right] \qquad\qquad [3]$$

30

11

In accordance with the preferred embodiment of the
present invention, the auxiliary function of the channel
estimation algorithm has been adapted to take into
account OFDM specificities. Indeed, the auxiliary
5   function has been rewritten as:

$$Q(H_m, H_m^{(p)}) = E_{x_m}\left[\log P(x_m, y_m, \tilde{H}^{(m)} \mid H_m) \mid y_m, H_m^{(p)}\right] \qquad [4]$$

where: $\tilde{H}^{(m)}$ stands for the vector H with a 0 on the mth
10   component. This allows, when estimating the channel
coefficient of the m-th sub-carrier, to use and take
advantage of the prior estimations of the channel
coefficients of the other frequency domain sub-carriers.

15   In addition, the Expectation step has been configured to
be an estimation of the probability on decoded bits,
which are needed for the M-step. These probabilities are
provided by any decoding scheme yielding soft outputs.
Furthermore, the preferred embodiment of the present
20   invention, proposes to use a turbo-demodulation
procedure, in order to optimise jointly the de-mapping
and the decoding steps. In this manner, the decoding
algorithm leads to a much better performance than a non-
iterative decoding scheme.
25
However, it is within the contemplation of the invention
that the inventive concepts herein described are
applicable to any convolutional encoder, i.e. it is
applicable for any rate and any puncturing scheme.
30   Furthermore, the decoding scheme of the present invention
can be applied to any encoded data that can be decoded by

12

a soft output decoder, i.e. any convolutional or turbo
decoder.

Referring now to FIG. 5, a block diagram model 500 of the
5   preferred channel estimation procedure is illustrated.
The received data stream 505 is demodulated in OFDM
demodulation function 510. The output from the
demodulation function 510 is input to a channel
estimation function, which incorporates an estimation
10 function 520 and a maximization function 550.

The OFDM demodulated signal is input to a de-mapping
function 525, which outputs de-mapped signals to a de-
interleaving function 530, and thereafter to a soft
15 output decoder function 535. In this manner, the channel
estimation function is operational over both the de-
mapping and decoding functions.

The de-mapping function in the preferred embodiment, i.e.
20 the function that associates a subset of bits to a
modulation constellation location, is able to operate
with any labelling map. For example, as shown in FIG. 6,
the de-mapping operation may be performed on a subset of
a 16-QAM signal, which is composed of four bits. Each
25 subset has to be associated to one of the sixteen
positions of the constellation. There are a number of
different ways to define the association function, which
affect the performance of the decoding system. For
example, constellation 610 in FIG. 6 illustrates a Gray
30 labelling structure, which is deemed optimum when a
Viterbi decoder is used. However, when turbo-
demodulation is used, an alternative mapping format such

13

as the set partitioning format 620 may provide better
results.

The output from the decoding function 535, is fed back to
5   the de-mapping function 525 via an interleaving function
540. The output from the improved estimation function
520 is input to a maximization function 550. The output
from the maximization function 550 is input to the de-
mapping function 525.
10

It is noteworthy that this arrangement also yields
decoded bits, in a bit-stream 535. The bit decisions are
made from decision function 560. Thus, the improved
channel estimation arrangement is a joint channel
15 estimation and decoding scheme.

In accordance with the preferred embodiment of the
present invention, the channel estimation operation has
been adapted to take into account the OFDM specificities,
20 using the coded bits on neighbouring frequency channels

Referring now to FIG. 7, a block diagram of a parallel
equivalent representation of a cyclic-prefix OFDM
modulator-demodulator 700 is illustrated. In effect, an
25 OFDM transmitter wishes to emit a set of bits $\{b_n^{(m)}\}_{\substack{1 \leq m \leq M \\ 1 \leq n \leq N}}$ 702

over a channel $\{h_l\}_{1 \leq l \leq L}$ using, say, a 2^N-QAM scheme 704.

First every subset of N bits $\{b_n^{(m)}\}_{1 \leq n \leq N}$ 702 is modulated
into a symbol x_m. In the OFDM context, the $\{x_m\}_{1 \leq m \leq M}$
30 symbols 706 are transformed from a frequency domain
representation into a time domain using an inverse fast

14

fourier transform (IFFT). The time-domain signals are
then serialized and convolved by the channel filter. The
signals are effectively corrupted by noise $\{n_m\}_{1 \leq m \leq M}$ 732
before they are finally returned into the frequency

5   domain using a FFT (not shown) to produce an output
signal $\{y_m\}_{1 \leq m \leq M}$ 734.

It is noteworthy that in a standard OFDM transmitted
signal, the signal is confined into a spectrum mask by

10 precluding some carriers from being used, especially the
ones at the top and the bottom of the FFT. In this
regard, such carrier values are set to zero.

An important characteristic of OFDM communication

15 systems, utilised in the preferred embodiment of the
present invention, is that OFDM systems are dimensioned
so that the length of the channel impulse response
('CIR') is smaller than the cyclic prefix size.
Accordingly, it is possible to use the classical OFDM

20 system model representation of FIG. 7.

Let us consider the case where h is a vector of M
independent variables, with its first L components being
L independent Rayleigh fading values with variance σ_l^2, l

25 $= 1, \ldots, L$. Let us further assume that the M-L other
components are independent Rayleigh fadings with a small
variance ε^2.

If the variance ε is small enough, h has been determined

30 as providing a reasonably good model of the time domain

15

channel. This leaves the frequency domain channel as
being represented by:

$$H = Fh, \quad \text{with} \quad F = \frac{1}{\sqrt{M}} \left[e^{-2i\pi \frac{lk}{M}} \right]_{(l,k) \in [1,M]^2} \qquad [5]$$

5

In accordance with the preferred embodiment of the
present invention, let us define a new auxiliary function
that provides an improved estimate of a channel
coefficient H_m. It is noteworthy that the improved

10   channel estimate considers the channel coefficients on
all other carriers in order to refine/track the primary
channel coefficient.

The inventors have appreciated that knowledge of the

15   channel coefficients from other carriers is useful, as
the decoder needs an estimate of the frequency channel
coefficients $\{H_m\}_{1 \le m \le M}$ to eradicate the channel effects
from the received coded bits. Indeed, in the preferred
embodiment of the present invention, the frequency

20   channel coefficients from the Fourier transform of the
time channel coefficients $\{h_l\}_{1 \le l \le L}$ are utilised in this
regard.

Thus:

25        $\underline{H} = F\underline{h}$ [6]

Where:

        $\underline{H}$ is a column vector of $\{H_m\}_{1 \le m \le M}$,

        $\underline{h}$ is a column vector of $\{h_l\}_{1 \le l \le L}$ filled with zeros

for the $M - L$ last coefficients, and

16

F is a '$M \times M$' matrix filled with Fourier coefficients.

At the opposite end of the time domain, the values of
5   elements of $\underline{H}$, are unknown. Indeed, due to the introduction of white noise in the model, it can be readily assumed that all of the elements are corrupted.

The inventors of the present invention have appreciated
10 that a standard channel estimation method, such as

$\hat{H}_m = \dfrac{y_m}{x_m}$, where x_m is a known symbol, leads to a poor

result.

In contrast, the proposed method of using the knowledge
15 of the channel coefficients from other carriers helps to refine the values of channel estimate. In particular, the definition of the statistical model h and the cost function are key distinguishing features of the inventive concepts of the present invention.
20

Thus, in the auxiliary function, we add $\tilde{H}^{(m)}$ in the following manner:

$$Q(H_m, H_m^{(p)}) = E_{x_m}\left[\log P(x_m, y_m, \tilde{H}^{(m)} \mid H_m) \mid y_m, H_m^{(p)}\right] \qquad [7]$$

25

Where:

$\tilde{H}^{(m)}$ stands for the vector H with a 0 on the mth component.

17

The maximization of this function leads, after some
computational effort, to the following channel estimate
update formula:

$$5 \quad H_m^{(p+1)} = \frac{\sum_{x_m} \mathrm{P}\left(y_m | x_m, H_m^{(p)}\right) \mathrm{P}(x_m)\left[y_m \overline{x_m} - \sigma^2 \left(\Delta_{SH}^{-1}\right)_m \widetilde{H}^{(m)}\right]}{\sum_{x_m} \mathrm{P}\left(y_m | x_m, H_m^{(p)}\right) \mathrm{P}(x_m)\left[|x_m|^2 - \frac{\sigma^2}{\upsilon^2} + \frac{\upsilon^2}{\gamma^2}\right]} \qquad [8]$$

where:

$$\gamma^{-2} = \left[\Delta_{SH}^{-1}\right]_{(m,m)}, \quad \Delta_{SH} = SF^*\mathrm{Diag}([\sigma_1^2 \cdots \sigma_L^2 \varepsilon^2 \cdots \varepsilon^2])FS^T \quad [9]$$

and

$$10 \quad \upsilon^2 = \frac{1}{M}\left[\sum_{l=1}^{L}\sigma_l^2 + (M-L)\varepsilon^2\right]. \qquad [10]$$

S is the information carriers selection matrix. When
dealing with a full sub-carrier OFDM symbol, γ^{-2} can be
rewritten into:

$$15 \quad \gamma^{-2} = \frac{1}{M}\sum_{l=1}^{L}\sigma_l^2 + \frac{M-L}{M}\varepsilon^2. \qquad [11]$$

It is noteworthy that the general expression of γ^{-2} of
equation [9] takes into account the fact that some sub-
carriers are not used, which is always the case in
20 practice.

In practice, three parameters are needed to implement the
aforementioned formula, namely: $\mathrm{P}(y_m | x_m, H_m^{(p)})$, $\mathrm{P}(x_m)$ and
$\widetilde{H}^{(m)}$.

25

18

If we assume that the channel additive noise is a
Gaussian white noise of variance σ^2, $P(y_m \mid x_m, H_m^{(p)})$ may be
viewed as:

$$P(y_m \mid x_m, H_m^{(p)}) = \frac{1}{\pi\sigma^2} e^{\frac{\left|y_m - H_m^{(p)} x_m\right|^2}{\sigma^2}} \qquad [12]$$

5

Where:

$P(x_m)$ is the product of the probabilities of each
coded bit involved in the symbol x_m. The turbo-
demodulation process provides an estimation of these

10 probabilities. Thus, $P(x_m)$ is the result of the E-step;
and

$\widetilde{H}^{(m)}$ is unknown, but each of its component $\widetilde{H}_i^{(m)}$ may
be taken as the current estimate of the channel

15 coefficient, i.e. $\widetilde{H}_i^{(m)} = H_i^{(p+1)}$ for $i < m$ and $\widetilde{H}_i^{(m)} = H_i^{(p)}$ for
$i > m$.

However, the inventors of the present invention have
recognised that the above methodology would lead to the

20 last set of coefficients being estimated more accurately
than the first set of coefficients. Hence, to remove
this drawback and improve the estimation, the inventors
propose implementing a 'forward-backward' procedure to
further improve the channel refinement.

25

The preferred implementation of the forward/backward
process is illustrated in FIG. 8. The channel refinement
is performed on a carrier-by-carrier basis. Received
data is input to the Turbo demodulation estimation

process 804, as illustrated in FIG. 6. Furthermore, the
received data is also input to the maximization process
806, which comprises an algorithm having two steps, i.e.
one 'forward' step 808 and one 'backward' step 810. The
5   operation of the forward step 808 and the backward step
810 is performed on the received data and the channel.
estimation values output 812 from the estimation
algorithm 804. The operation of the forward step 808 and
the backward step 810 is performed making bit decisions
10   814 using the information bit probabilities. The output
of the process is a sequence of received bits 816.

In accordance with the preferred embodiment of the
present invention, the forward step is implemented as
15   follows:
        The H_m coefficients are estimated from $m=1$ to $m=M$.

In this step, when computing the channel coefficient on
sub-carrier m, the channel coefficient estimates on the
20   other sub-carriers l, such that $m<l\leq M$, come from the
previous iteration. The channel coefficient estimates on
the other sub-carriers l such that $1('one')\leq l<m$ come from
the actual iteration.

25   The backward step is implemented as follows:
        The H_m coefficients are estimated from $m=M$ to $m=1$,
using the estimates of the forward step.

In this step, when computing the channel coefficient on
30   sub-carrier m, the channel coefficient estimates on the
other sub-carriers l such that $m<l\leq M$ come from the
forward step, and the channel coefficient estimates on

20

the other sub-carriers l such that l('one')≤l<m come from
the present backward step.

In this manner, approximately the same level of accuracy
5   of each channel coefficient can be achieved, thereby
improving the channel estimate performance.

To fully evaluate the performance of this method, a set
of Monte-Carlo simulations was performed over two hundred
10   channels to estimate the bit error rate (BER) and the
packet error rate (PER). The simulation context was
performed using one hundred OFDM symbols of sixty-four
sub-carriers preceded by two pilot symbols. This is
useful in obtaining a first channel estimate. The
15   simulation was performed over sixteen independent
Rayleigh fading channels. A half rate convolutional
encoder (035, 023) was used. Symbols were bit-
interleaved with a random pattern and modulated by a 16-
QAM constellation.
20

The results of the simulation are illustrated in FIG. 9
and FIG. 10. Referring now to FIG. 9, a comparison of
the average BER versus signal to noise ratio (SNR) is
illustrated for an OFDM system. FIG. 10 illustrates a
25   comparison of the average PER versus SNR for the OFDM
system.

In both FIG. 9 and FIG. 10, the OFDM system does not
refine channel estimates and performs only two iterations
30   of the turbo-demodulator per global iteration. Three
curves are shown:

21

(i) A first curve indicates the performance without
employing the inventive concepts herein before described,
identified as 'NONE 2 TD';

(ii) A second curve illustrates the performance when
5   implementing the proposed invention, identified as '1 EM-
OFDM-SS 2 TD for $\varepsilon^2=3e^{-3}$; and

(iii) A third curve illustrates the performance when
implementing the proposed invention, identified as '1 EM-
OFDM-SS2 2 TD' for $\varepsilon^2=1e^{-16}$.
10

It is noteworthy that, by implementing the inventive
concepts herein described, an improvement of around 2dB
in BER/PER can be achieved. Moreover, provided that the
variance ε parameter is small enough the setting of the
15 parameter is not critical. Hence, the user does not have
to perform precise tuning on the variance ε parameter.

It is within the contemplation of the invention that the
aforementioned inventive concepts can be applied to any
20 element in the communication system that performs
decoding and channel estimation, for example a BTS
communication unit and/or a MS.

In the preferred embodiment of the present invention, the
25 maximization step utilises a forward-backward approach.
However, it is within the contemplation of the invention
that alternative maximization techniques may be used in
the decoder such that the decoder is still able to
benefit from the inventive concepts described herein.
30

22

It will be understood that a method of channel estimation
performed by a communication unit operating in an OFDM
communication system as described above, tends to provide
at least some of the following advantages:

5

(i) A mechanism to perform jointly de-mapping,
decoding and channel estimation is described, whereby
their performance can be globally optimised. In
particular, the modification of the EM cost function

10   results in the modification of the channel update
formula, which provides an improved decoding performance.

(ii) There is no estimation error in a noiseless
case. In practice, this means that the proposed
15   estimator performs better than the strongest-path method
based estimator for high SNR conditions.

(iii) Estimation noise is partially removed from the
selected channel coefficients.

20

(iv) There is minimal additional complexity when
compared to prior art arrangements.

(v) The inclusion of OFDM specificities in a novel
25   and inventive approach enables bit-interleaved coded
modulation improvements proposed by J. Boutros et al. to
be translated to an OFDM scenario. In particular, the
inventive concepts can be applied to any kind of mapping,
and does not use pilot carriers. Nevertheless, the
30   inventive concepts hereinbefore described may be used in
the presence of pilot carriers, if desired.

23

Whilst specific, and preferred, implementations of the
present invention are described above, it is clear that
one skilled in the art could readily apply further
variations and modifications of such inventive concepts.

5

Thus a method of channel estimation performed by a
communication unit operating in an OFDM communication
system has been provided wherein at least some of the
aforementioned disadvantages with prior art arrangements

10 have been alleviated.